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The subpubic angle in sex determination: Anthropometric measurements and analyses on Anatolian Caucasians using multidetector computed tomography datasets

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ABSTRACT

Introduction and aim: The investigation of new anatomical criteria and revalidation of existing ones in sex determination for different populations are among main research foci of forensic anthropometry. In that context, the pelvis is the most extensively studied bone. A number of qualitative classifications, dimensional measurements and indices have been proposed for investigative anthropometry and forensic studies. Independent use of these parameters generally provided an accuracy rate of 70–75%. In this study, the accuracy rate of the subpubic angle in sex determination was investigated in living Anatolian Caucasians.
Material and method: The subpubic angle was identified and measured on three-dimensional computed tomographic images of pelves. Data were obtained using 64-detector computed tomography (MDCT) with an isotrophic resolution of 500 μm. The sample included 66 males (41.6 ± 14.9 years of age) and 43 females (41.1 ± 14.2 years of age). Measurements were taken on a dedicated three-dimensional image analysis workstation. The subpubic angle was electronically measured. The technique and methodology was validated on a standard skeletal model. Intraobserver agreement was analyzed with intraclass correlation coefficient, and intraobserver variability was evaluated with technical error of measurement (inter- and intra-observer TEM), relative technical error of measurement (rTEM) and coefficient of reliability (R) measures. The subpubic angle for the study group and for both sexes was reported as minimum–maximum (mean ± SD). Independent-Samples T Test for equality of means was used to determine the difference between the two sexes regarding the subpubic angle. The correlation between the subpubic angle and the age of subjects were using Pearson Correlation Coefficients in males and in females. Logistic regression model was used to classify subjects according to their sex. Receiver operating characteristic curve analysis was performed to determine a cut-off value for further studies and to test the performance of the binary classification test.
Results: Intraclass correlation for the subpubic angle (0.990), TEM (1082), rTEM (1.492), and R (0.990) represented almost complete reliability and accuracy of the measurement method. The subpubic angle was between 48° and 81° (65.9° ± 7.2°) in males and was between 64° and 100° (82.6° ± 7.7°) in females. Statistically significant difference was found between males and females regarding the subpubic angle ($p < 0.0001$). The subpubic angle was not significantly correlated with age in males ($p = 0.953$), or in females ($r = 0.975$). The accuracy of the subpubic angle in sex determination was 90.8%. With a cut-off value of 74°, sensitivity of subpubic angle to detect female phenotype was 88% and its specificity was 95%.
Conclusion: The subpubic angle is an accurate parameter in sex determination with high sensitivity and specificity.

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1. Introduction

The determination of sex using isolated bones and their remnants is one of the necessary steps in forensic investigations.[1] At first glance, this seems to be an easy task due to the presence of only two sex types and gross morphological differences. Methods that rely on subjective assessment of these differences are known as visual methods for which the pelvis has long been regarded as the most critical structure.[2] In that context, the subpubic angle, the sciatic notch, the preauricular sulcus, the auricular area and many other pelvic structures were reported to exhibit sex dependent morphological differences.[2–4] These differences are mainly due to responsiveness of pelvis to sex hormones; the presence of sexual dismorphism is related to childbirth. However, visual methods that may be used in sex determination were based on an almost stereotypic male and/or female and are for ultra-masculine and ultra-feminine pelves.[2] In daily practice, therefore, these morphological features, in isolation, may not always be prominent to establish a firm conclusion of the sex type. Although several criteria were combined to improve accuracy,[3,5,6] the presence of large overlaps, and the presence of a possible bias due to the overwhelming number of males in skeletal collections[2] limit the use of visual methods.

Metric methods constitute a more scientific approach to the determination of sex.[2] These methods rely on measurements and they therefore avoid many observational controversy. For pelvis, metric methods are used since the introduction of pelvic index by Turner (1885).[7] They are either in the form of basic measurements (iliac breadth, pubic height, etc.), or complex indices (ischium-pubis index, acetabulum-pubis index, etc.).[2,4,8–10] Even metric methods, however, are prone to racial and chronological variability. Therefore, these methods have to be adapted to different populations and standards should be used with reference to the group from which they were drawn and upon which they are based.[2]

Visual assessment of the subpubic angle is reported to be one of the most reliable pelvic parameters in the determination of sex, and it produces acceptable results even in the hands of inexperienced researchers.[6,11] However, reports regarding the quantification of this parameter in either or both sexes are surprisingly few,[5,9,10,12–14] and were conducted using a variety of techniques and procedures. In that context, metric data on Anatolian Caucasians are also missing.

The aim of this study was to determine the subpubic angle in Anatolian Caucasians, to test its accuracy in the determination of sex and to determine a cut-off value to be used to discriminate between both sexes. This parameter was measured on a digital collection of high resolution datasets acquired with multidetector computed tomography (MDCT). This new radiological technique enables researchers to perform anthropometric studies on living humans noninvasively, and allows them to store large amount of data electronically and re-interpret it at any time, at any place.[15–17] High resolution virtual anthropometry, used in the study, is an optimal alternative to the population studies where the number of well-protected cadavers is limited or unavailable. This technique constitutes an extension to the accepted digital radiological techniques such as scan projection radiography that is performed using conventional CT.[18]

2. Materials and methods

2.1. Study sample

The virtual human collection that was used in the study was consisted of high-resolution multidetector computed tomography data of 109 Caucasian adults living in Eastern Anatolia. In the study group there were 66 males (41.56 ± 14.86 years of age) and 43 females (41.14 ± 14.15 years of age). Males were 160–190 cm (172.3 ± 6.3) in height and 53–116 kg (76.1 ± 12.3) in weight.

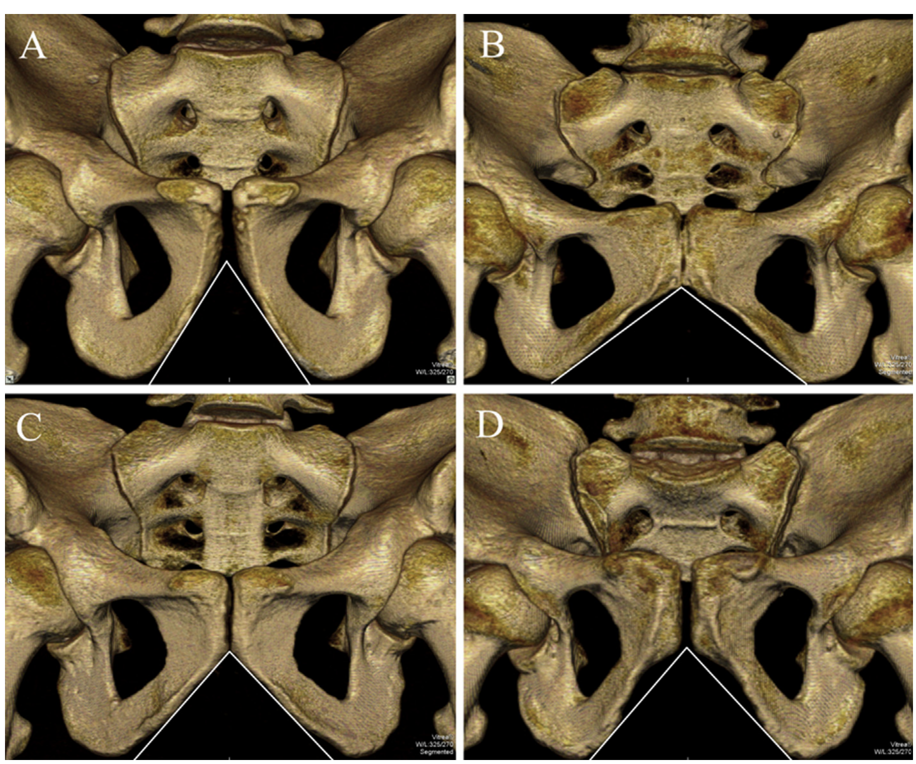

Fig. 1. Top row: Volume-rendered three dimensional MDCT images of a stereotypic male (A) and a female (B). Subpubic angle of the female subject is significantly larger than the male subject. Bottom row: Volume-rendered three-dimensional MDCT images of border types. Sex determination was not possible by metric method.

Females were 148–170 cm (160.1 ± 5.4) in height and 45–115 kg (70.5 ± 13.0) in weight. The subjects were healthy donor candidates for living donor living transplantation and they had undergone extensive preoperative clinical, laboratory and radiological workups during which their upper and lower abdomens had been volumetrically scanned. The study was funded by Inonu University Scientific Research Projects Fund under umbrella project on MDCT research laboratory and under respective subproject on forensic MDCT researches (Grant no: I.U. BAP 2005 GUZ-1/GUDUMLU). The institutional ethical permission was obtained (Protocol no: 2008/78). The dataset was previously used in another anthropometric study.[19]

2.2. Imaging protocol and measurement

Imaging was performed with a 64-detector MDCT scanner (Aquilion 64, TSX101-A, Toshiba, Japan). Bony pelvis was scanned helically with a standard technical parameters. In that setting, an isotropic spatial resolution of 0.5 mm and an in-plane spatial resolution of 390 μm were obtained. Volumetric datasets were processed on a dedicated image analysis workstation (Vitrea fX 6.3, Vital, USA) with advanced 3D volume rendering and advanced 2D and 3D tissue segmentation algorithms. Bony structures were automatically segmented. Manual dissections were performed to eradicate any remaining soft tissues and osseous spurs. Pubic arc was visualized on volume rendered image (Fig. 1). Two lines were electronically drawn between the inferior borders of the pubic rami and the point located on inferior midline of the interpubic disc[14,20] (Fig. 1). The angle between two lines was measured automatically measured by the image analysis software. Post-processing of the image data and electronic measurements were performed by the first author who was highly experienced on the analysis hardware and software. For the calculation of technical error of measurement the measurements were repeated twice in two different days. For the descriptive statistics only mean values were used for each of the subjects.

2.3. Validation of the measurement on standard skeletal model

Before the analysis of the actual datasets, an experimental study to test the validity of the virtual measurement was tested using a male pelvic skeletal model (A60, 3B Scientific GmbH, Germany). The model had dimensions of 18 × 28 × 23 cm, and weighted 0.8 kg. It consisted of hip bone, sacrum with coccyx and two lumbar vertebrae as well as pubic symphysis. Radiodense steel cannula of a biopsy needle was shaped to form an angle that matched to the subpubic angle of the A60 pelvic skeletal model and was attached on the model. The model was scanned using similar scan parameters to the subjects. The actual angle of the cannula was subsequently measured using a goniometer. The volumetric CT data of the model was analyzed on the Vitrea fX workstation. The cannula was identified on the three dimensional images and its angle was measured electronically as described above. The actual subpubic angle of the male pelvic skeletal model that was measured with goniometer was identical (60°) to the subpubic angle that was electronically measured on digital dataset.

2.4. Statistical analyses

Measurements were taken to the nearest degree. All data were subjected to statistical analysis using SPSS Statistics, release 17.0.1.0. The mean, standard deviation, and range for each set of measurements were calculated for each group.

Two methods were used to describe anthropometric measurement error. Intraobserver agreement was initially analyzed with the reliability measures. The reliability was tested using the intraclass correlation coefficient.[21] This coefficient produces measures of consistency or agreement values within cases. For calculations two-way mixed effects model with absolute agreement was used. The values for reliability coefficient range from 0 to 1. A coefficient of below 0 indicates "no reliability", >0–<0.2 is slight reliability, 0.2–<0.4 is fair reliability, 0.4–<0.6 is moderate, 0.6–<0.8 is substantial and 0.8–1.0 is almost perfect reliability.[22]

The technical error of measurement (TEM) is another accuracy index to express the error margin in anthropometry. The TEM index allows researchers to verify the accuracy degree when performing and repeating anthropometrical measurements (intra-observer) and when comparing their measurement with measurements from other anthropometrists (inter-observer). The TEM index, which is the standard deviation between repeated measures was used for the calculation of the intra-observer variability – variation of repeated measurements of a group of subjects performed by the same researcher.[23] It is important observing that the lower the TEM obtained, the better is the accuracy (or reliability) of the researcher to perform the measurement. Intra-observer TEM calculation was performed according to the method described by Goto and Mascie-Taylor (2007)[23] and Perini et al. (2005).[24] The difference between the 1st and 2nd measurements was determined (deviation between them) for all volunteers measured by the same researcher. Then the deviations (D) obtained were raised to the second power. The results were summed and divided by two times the number of subjects (N) in order to obtain the absolute TEM (Formula 1). Absolute TEM was interpreted as the typical magnitude of error associated with an angle measurement and was used to estimate intraobserver precision.

$$\sqrt{\frac{\sum D^2}{2N}} \tag{1}$$

The absolute TEM was transformed into relative TEM (rTEM) in order to obtain the error expressed as percentage corresponding to the total average of the variable to be analyzed using the Formula 2. Relative TEM represented an estimate of error magnitude as a percentage of object size. In this stage the variable average value (VAV) was calculated by obtaining the arithmetic mean of the mean between both measurements obtained (1st and 2nd measurements) of each volunteer for the subpubic angle. After the calculation of the rTEM, for intra-observer analysis, it was classified as acceptable or nonacceptable using beginner anthropometrist cut-off values (<1.5%) for "other measures".[25]

$$\%\mathrm{TEM} = \frac{\mathrm{TEM}}{\overline{X}} \times 100 \tag{2}$$

Using the formula 3, the coefficient of reliability R was determined, which ranges from 0 (not reliable) to 1 (complete reliability). Although there are no recommended values for R, Ulijaszek and Kerr (1999)[26] suggested that a cut of value of 0.95 be used (i.e. a human measurement error of up to 5%). R represents the proportion of between-subject variance free from measurement error.

$$R = 1 - \left(\frac{\mathrm{TEM}^2}{\mathrm{SD}^2}\right) \tag{3}$$

Independent-Samples T Test for equality of means was used to determine the difference between the two sexes regarding the subpubic angle. The correlation between the subpubic angle and the age of subjects were using Pearson Correlation Coefficients in males and in females. Logistic regression model was used to classify subjects according to their sex. Receiver operating characteristic curve analysis was performed to determine a cut-off value for

Table 1
Summary of descriptive statistics for subpubic angle.

Sex	Sample size (n)	Minimum (degree)	Maximum (degree)	Mean (degree)	Std. dev. (degree)
Males	66	48	81	65.9	7.2
Females	43	64	100	82.6	7.7
Both	109	48	100	72.5	11.0

further studies and to test the performance of the binary classification test. $P < 0.05$ was accepted as the level of significance.

3. Results

In the sample, the subpubic angle was found to be between 48°–100° (72.5° ± 11.0°). In males, this angle was between 48°–81° (65.9° ± 7.2°). In females, it was between 64°–100° (82.6° ± 7.7°).

For measurements taken by the same observer intraclass correlation for the subpubic angle (r) was 0.990 ($r = 0.986$ for lower bound and $r = 0.993$ for upper bound with 95% confidence interval). According to Bland and Altman (1986)[22] a r value of 0.8–1.0 represents an almost perfect reliability and the intraclass correlation for the subpubic angle measurements in this study meant strong correlation between measurements by the investigator on two separate occasions.

For measurements taken by the same observer TEM was 1.082, VAV) was 72.472 and the rTEM was 1.492. The rTEM value was classified as acceptable using cut-off values (<1.5%) for "other measures".[25] The R was found to be 0.990, which represented almost complete reliability ($R = 1.0$). This value is above the cut of value of 0.95 to be used according to Ulijaszek and Kerr (1999).[26]

There was a significant difference between males and females regarding the subpubic angle (Independent-Samples T Test for equality of means, $p < 0.0001$) (Table 1, Fig. 2). Age was investigated as a contributing factor in the subpubic angle but a statistical correlation was not found between these parameters in males (Pearson Correlation Coefficients, $p = 0.953$) or in females (Pearson Correlation Coefficients, $p = 0.975$).

Binary logistic regression was used to predict the sex using the subpubic angle. According to statistical analysis, the mean overall accuracy of the subpubic angle on the classification of the subjects according to their sex was 90.8% ($p < 0.0001$). With that analysis, 63 of 66 males (95.5%) and 36 of 43 females (83.7%) were correctly classified according to their sex (Table 2). According to ROC curve analysis, a cut-off value of 74° for the subpubic angle correctly predicted female subjects with 88% sensitivity and 95% specificity. That is 88% of female subjects were correctly predicted as female, and only 5% of male subjects were erroneously identified as female. As for any test, there is a trade-off between the sensitivity and specificity, and correctly predicting %95 of females as female requires a cut-off value of 70° and includes erroneous classification of 35% of males as female.

4. Discussion

In forensic anthropology, the development of new methods of sex determination from skeletal remains constitute a major line of research. Another line concentrates on the improvement of existing methods. Current studies, usually employ metric methods to allow discriminant analyses and cut-off values that would later be used in actual scenarios.[1] Ideally, bone remnants are essential to build standards for metric studies. But the presence of limited number of skeletal remnants and the difficulties of obtaining these materials restrict the researchers on many instances.[18,27] In this context,

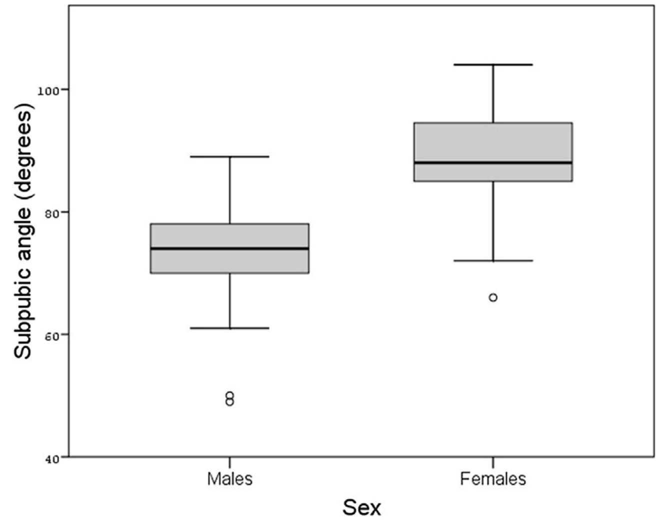

Fig. 2. Boxplot graph showing the distribution of subpubic angle between in males and in females.

MDCT technology offers to researchers three dimensional representation of the human skeleton with excellent spatial resolution.[19] With that technique, high quality imaging of the living subjects and noninvasive observations became possible. Radiographies in general, and MDCT in particular enable researchers to perform measurements on virtual bones instead of fresh bones. Fresh bones are extremely limited in number and they require an extensive preparation including the process of defleshing. On virtual skeletons, on the other hand, detailed analyses of anatomic structures can be performed in any time, at any place as long as the digital data are kept electronically.

The pelvis is one of the most widely used bones in anthropometric studies. The subpubic angle of the pelvis is a well-known visual criteria for sex determination. A convex or straight pubic contour suggests male, whereas a concave contour suggests female.[6,28,29] The former appearance is called "V-shaped", and the latter is called "U-shaped".[30] These features are best seen from the dorsal aspect of the pubis and ischio-pubic ramus. From that projection, a lateral recurve which occurs in the ischio-pubic ramus of the female at a short distance below the lower margin of the pubic symphysis is absent in the male pelvis.[6] However, it is difficult to observe these characteristic appearances in every case to establish a firm conclusion. In that context, some males may even show a slight concavity of pubic contours.[6] Although the number of ambiguous cases are low, it must be noted that the discriminatory value of that criteria is significantly race dependent, and is probably more reliable in Whites.[11,28]

In the presence of ambiguous cases, employment of metric method may improve the accuracy of the subpubic angle in sex determination. According to Washburn (1948), the pubic bone is the pelvic part which is most responsive to the action of female hormones and the subpubic angle increases during the growth in females.[31] Traditionally, a subpubic angle less than 90° indicates a

Table 2
Classification table for sex using the subpubic angle.

Observed membership	Predicted membership		
	Male	Female	Percentage correct
Male	63	3	83.7
Female	7	36	95.5
Overall classification accuracy (%)			90.8

Table 3
Subpubic angle in various races and populations as reported by researchers.

Authors	Country	Race	Materials	Method	Number of males	Subpubic angle in males	Number of females	Subpubic angle in females
Igbigbi and Nanono-Igbigbi, 2003[20]	Uganda	African Black	Living subjects	Anteroposterior radiographs	110	93.9 ± 21.1	95	116.1 ± 17.8
Igbigbi and Nanono-Igbigbi, 2003[20]	Malawi	African Black	Living subjects	Anteroposterior radiographs	73	99.2 ± 15.7	46	129.1 ± 14.2
Handa et al., 2003[27]	USA	American White	Living subjects	Axial MRI datasets	None	None	59	83.0 ± 0.8
Ridgeway et al., 2008[14]	USA	American White	Hamman-Todd collection	Digitization of reassembled bones	None	None	49	73.0 ± 11.1
Ridgeway et al., 2008[14]	USA	American Black	Hamman-Todd collection	Digitization of reassembled bones	None	None	47	77.1 ± 13.1
Tague, 1992[10]	USA	American White	Hamman-Todd collection	Projection images	50	63.7 ± 7.8	50	88.4 ± 12.3
Tague, 1992[10]	USA	American Black	Hamman-Todd collection	Projection images	50	65.8 ± 8.7	49	85.2 ± 10.4
Tague, 1992[10]	USA	Amerindian	Indian Knoll	Projection images	74	73.8 ± 8.4	58	98.1 ± 8.4
Tague, 1992[10]	USA	Amerindian	Pecos Pueblo	Projection images	104	61.6 ± 8.2	114	86.0 ± 10. 0
Tague, 1992[10]	USA	Amerindian	Libbon	Projection images	46	68.8 ± 7.8	21	95.2 ± 10.8
Tague, 1992[10]	USA	Amerindian	Haida	Projection images	29	65.4 ± 8.2	19	93.0 ± 12.3
Oladipo, 2010[35]	Nigeria (Ikwerres)	African Black	Living	Projection images	85	100.25 ± 7.8	173	119.38 ± 3
Oladipo, 2010[35]	Nigeria (Kalabaris)	African Black	Living	Projection images	129	105.38 ± 9	213	125.0 ± 3.2
Karakaş et al.	Turkey	Caucaisan White	Living	3D MDCT datasets	66	65.9 ± 7.2	43	82.6 ± 7.7

male phenotype, whereas an angle more than 90° indicates a female phenotype.[1] However, this cut-off value is very crude and has significant overlap around it. These factors complicate sex determination, and necessitate the definition of more refined and population-specific cut-off values. However, the literature data on subpubic angles in males and/or in females are surprisingly few in number and the ones that report both sexes independently in contemporary populations are usually for Blacks.[10,14,20,32] As population differences are known to affect the expression of sexual dimorphism, new studies on different populations must be conducted to find population-specific discriminatory values.[2]

The subpubic angle has been measured in various populations using different methods (Table 3). The present study used MDCT datasets to determine subpubic angles. MDCT scanners use finely calibrated detectors with very high spatial resolution. Computed tomographic images are free of projectional variabilites that are encountered on projection (plain film) radiography. Measurements that are performed on these images, are very close to the measurements performed on real structures using conventional methods. In this study, therefore, the measurements were compared with the conventional data that were obtained from cadaveric collections. Accordingly, the mean subpubic angle of Anatolian Caucasian females was significantly higher than the mean subpubic angle of white or black females (83° vs. 73° and 77°).[14] The mean subpubic of Anatolian Caucasian males was significantly lower than the mean subpubic angle of Anatolian Caucasian females (66° vs. 83°). The mean subpubic of Anatolian Caucasian males on the other hand is close to the mean subpubic angle for white American females.[14] A priori knowledge about the ethnical background, therefore, is necessary to make an inference about phenotype. When the ancestry is known (e.g. Anatolian Caucasian), the accuracy of subpubic angle in sex determination (90.8%) is almost equal to or higher than the accuracy values reached by solitary use of many pelvic indices and ratios. For example, with acetabulum-pubis index only 83% of males and 81% of females can be correctly discriminated.[32] The use of superior pubis ramus length may provide an accuracy of 90–98.5%, the highest rate reached by a single parameter.[33] The combined use of a number of parameters may provide higher accuracy rates in sex determination. In this context, the combined use of nine parameters (iliac breadth, total height, pubic height, width of greater sciatic notch, acetabulum diameter, pubic length, ischial length, pubic width), correctly classifies 98% of white females, 93% of white males, 97% of black males and 91% of black females.[13] However, the subpubic angle still is a reasonably accurate single parameter with a relative ease of measurement.

Researchers have to bear four potential limitation in mind when using the subpubic angle in sex determination, and when comparing the results of different studies.[34] The first limitation is the possible effect of age on the subpubic angle. In Nigerians, the subpubic angle was found to be significantly greater in the older age group than in younger age group. In that study, the subpubic angle of younger and older subjects were compared using Student's *t*-test.[12] In our study, being conducted on male and female subjects with similar mean age and standard deviation, the subpubic angle and the age were not significantly correlated in males or in females. Incongruence between the studies should be explained by use of different statistical methods. The second limitation is the use of different techniques by different researchers. Technical variations may create unrealistic data as one may encounter when using projection film radiography, and may make a full comparison of the subpubic angle between races and populations impossible. A third limitation is the necessity to have the sacrum and both pelvic bones to measure. It is impossible to construct the subpubic alignment, in vitro, without these three components. A fourth and perhaps the most important limitation of any pelvic measure is that the sex determination is only possible on adult skeletons because preadolescent children do not exhibit major sexual dismorphism.[2] In that context, subpubic concavity is not well developed until the age of 20 years in females.[6] Therefore, the present study was conducted on adults and its findings should not be used on sub-adult material.

To summarize, this study reports in-vivo anthropometric data on the subpubic angle for contemporary Anatolian Caucasian males and females. It provides a sensitive and specific cut-off value that may be used in sex determination. In that context a pelvic bone with a subpubic angle of less than 74° is more likely to belong to a male, whereas a pelvic bone with a subpubic angle of more than 74° is more likely to belong to a female. The study also demonstrates the use of MDCT in forensic medicine to collect data on different populations to determine geographical, ethnical and diachronic

variances. This medical instrument with high precision consist an important part of the armamentarium of forensic anthropology laboratories in analyzing human skeletal anatomy, its morphologic variations and its pathological changes. In forensic studies, the collection of normative data will probably constitute one of the most important uses of MDCT, next to virtual autopsy.

Ethical approval

The institutional ethical permission was obtained (Protocol no: 2008/78).

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Conflict of interest

No conflict of interest was reported.

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